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Sciences

Submitted Abstracts

Title Wavefront sensing experiments using an optimised common path interferometer

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Abstract We have developed a new general approach that can be applied to analysis and optimisation of a wavefront sensing scheme based on spatial frequency filtering in a common path interferometer (CPI) configuration. In a CPI, a part of the incoming wavefront is extracted and perturbed to generate a so-called synthetic reference beam for interference with the remainder of the wavefront. We demonstrate experimentally the application of the algorithms, generated in our theoretical treatment, to the optimisation of a CPI and explain how this can be applied to the generic class of such interferometers.

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DEPT OF PHYSICS

AQF00-11-3787

Title **Innovative Low Cost Adaptive Optics Programs—A New M
Set Emerges**

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and Gary C. Loos

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Abstract Gone are the days of unfettered government spending. An affordable, high performance alternative to multi-million dollar adaptive optics systems is required by the scientific and industrial communities. We have constructed and now give early performance specifications for the 1st of three low cost Adaptive Optics systems for the University of Puerto Rico Imaging Interferometer. Built in months, not years, our in-house subsystem developments include (1) a photon counting ICCD Shack-Hartmann wavefront sensor; (2) a zero latency analog wavefront reconstructor; (3) a precision 2D geometry interpolator; (4) a 700Hz bandwidth beamsteering mirror system with photon counting tracker; and (5) a data acquisition, monitoring and deformable mirror control computer. Key to the control system is a 37-element MEM electrostatic membrane deformable mirror purchased from OKO Technologies. Every element of this system is innovative in the sense of exceptional high performance at low cost. We will discuss the applicability of using several unique 2D liquid crystal spatial light modulators as correcting elements. We will discuss feedback vs. feed-forward implementations of control law, as well as many practical considerations of full implementation. Other possible medical, industrial, and scientific applications of this affordable, high performance AO technology will be presented.

Title **Experimentation with curvature sensing**

Name Erez Ribak

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Address Department of Physics Technion Haifa 32000 Israel

Abstract To apply the transport of intensity to wave front sensing in the laboratory. Strong limitations on the accuracy of the method result from basic constraints.

Title **Demonstration of One-way Image Reconstruction Using Photorefractive BaTiO₃:Rh.**

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Abstract We have demonstrated image reconstruction via four-wave mixing the case of a signal making a single pass through a turbulent medium. Both the signal and the reference originate from the same source and propagate through the same turbulent medium. In the four-wave mixing process, phase aberrations are subtracted out. A read beam from a second source reconstructs the undistorted image. Good reconstructed image fidelity is demonstrated for both static and dynamic distortions. This technique is also used to measure the correlation length of the turbulence by varying the angle between the signal and the reference in the four-wave mixing scheme.

Title **Wave-front sensing in the multi-reference scheme and field-of-view-widening problem.**

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Abstract It is well established that adaptive optics is strictly limited by the anisoplanatic effect. The single wave-front reference provides the index-of-refraction-distribution information only along the on-axis-direction, that leads to the narrow isoplanatic patch. We develop an advanced correction method aimed at field-of-view widening. The method is based on the multi-reference scheme and utilizes the far-correlated statistical properties of the random medium. The feasibility and the application of the method require the modification of the wave-front sensing algorithm, that would provide independent determination of wave-front distortions from spatially separated guide stars. The wave propagation from the different point-like sources through an irregular medium and the corresponding wave-front distorting was numerically simulated and the special computer code was developed for that purpose. Using the program we demonstrate that the described correction method allows to significantly widen the effective field-of-view of the adaptive optical system.

Title **Modal wavefront sensing adapted to segmented primary mirrors of telescopes.**

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Abstract Modern astronomical telescopes rely on active optics to control shape and position of the primary and secondary mirrors in real time. This ensures that the image quality provided by the telescope will be maximized, whatever the telescope orientation or environmental conditions. Wavefront sensing is an integral part of all active optics schemes. The largest existing and planned telescopes employ segmented primary mirrors, which may complicate the wavefront sensing. We study the possibility of employing Shack-Hartmann arrays with lenslet geometries adapted to the segment shapes, and compare the performance of several such geometries. We also develop an optimal scheme for modal wavefront reconstruction.

Title **Dual wavelength dynamic holography**

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Abstract Dual wavelength holography, when the thin (plain) hologram is recorded at one wavelength and reconstructed at some shifted wavelength, is an efficient tool for many applications. Optically addressed liquid crystal spatial light modulators are very convenient for recording thin dynamic holograms and, in particular, for recording the dynamic dual wavelength holograms. On such a basis one can realize the dynamic interferometer, providing the arbitrary scaling of the wave front distortions. Such an interferometer can be rather helpful for many tasks of the adaptive optics, in particular: the simplification of the procedure of the measuring of the robust wavefront distortions (in this case one can analyse the interference pattern with the much less fine structure); the record of the dynamic holographic correctors, working in spectral ranges, where laser sources for holographic record are unavailable, in particular, in mid-IR range of spectrum; the extension of the range of distortions which can be corrected by means of the phase valve, mounted in negative optical feedback loop.

Title	Analogous correction for distortions using dynamic hologra in optically addressed liquid crystal modulators		
Name	Vladimir Yu.Venediktov, Vladimir A.Berenberg, Alexey A.Leshchev,Michael V.Vasil'ev		
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Abstract	Optically addressed liquid crystal spatial light modulators (OA I SLM) present a very good tool for recording the thin dynamic holograms with the short response time and high diffraction efficiency. Such holograms can be, in particular, used for correc for distortions in various kinds of imaging and beam directing systems, including microscopes, microlithography lenses etc. Th thin nature of such holograms (which are thus free of spectral an angular selectivity of volume holograms) makes it possible to correct for distortions in a rather wide spectral band. The paper presents the results of several years of theoretical and experimen study of OA LC SLM elements for the dynamic holography applications and their use for correction for distortions in severa kinds of optical systems.		

Title	Position and displacement sensing with low-cost Shack-Hartman wavefront sensors.
Name	Jorge Ares, Teresa Mancebo, Justo Arines, Susana Rios and Salvador Bara.
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Abstract	Besides specialized applications in the field of adaptive optics, Shack-Hartmann wavefront sensors are finding their way as versatile tools in laboratory and industrial environments. A certain increase in their market share can be expected in the following years, led by those applications in which they can compete successfully with traditional interferometric setups. Here we report the use of a low-cost wavefront sensor made with inexpensive diffractive microlenses and off-the-shelf CCD optics for position and displacement measurements of incoherent sources (LEDs). The position estimation algorithms as well as the required calibration procedures are described.

Title Wavefront slope filtering by spatial averaging in Hartmann sensors of random phase fields.

Name Salvador Bara (1), Julian Mayor (1), Susana Rios (1) and Valerii V. Voitsekhovich (2).

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Abstract Shack-Hartmann wavefront sensors working in low irradiance conditions require the use of microlens arrays with maximum sized and closely packaged subpupils, in order to get the best signal-to-noise ratio from available photons. There is yet another basic phenomenon by which bigger subpupils contribute to increase the accuracy of low-order modal wavefront estimation after turbulence: the spatial averaging of the wavefront slope taking place at each microlens. This effect is purely related to the geometrical properties of the sampling array and the statistics of the phase fluctuations, holding even in the limit of high photon fluxes. Here we describe the influence of averaging on the Zernike modal reconstruction errors both for Kolmogorov and non-Kolmogorov phase statistics with general-exponent power spectrum laws.

Title **Performance Study for In-Situ Calibration Methods of an Active Optical Control for a Segmented Aperture Optical System**

Name Timothy P. Murphy Richard G. Lyon, John E. Dorband Jan M. Ho

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Abstract Future large space based optical systems will most likely employ a segmented primary mirror in an active optical control system with wavefront sensing and reconstruction. We represent the wavefront this system by a linear combination of actuator influence functions. Errors are introduced if the influence functions drift due to environmental changes. For example, a space-based system may change due to gravity release. Furthermore, the linear theory is only approximation to the true system response. For operation outside its original calibrated region, a new linear approximation is required. A method of in-situ calibration is the controls methodology "system identification". We investigate the performance of active optical system identification algorithms for both problems and, as time permits, investigate algorithm performance with dynamical system disturbances such as jitter.

Title **Modal Wavefront reconstruction techniques**

Name Clelia ROBERT, Jean Marc CONAN, Laurent MUGNIER, Vincent MICHAU and Gérard ROUSSET.

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Abstract Modal Wavefront reconstruction techniques - A comparison The modal sensor is a key component of an adaptive optics system, which provides a real time correction of the turbulent wavefronts. Wavefront sensing is also useful for the image post-processing techniques such as deconvolution from wavefront sensing (DFWFS). This paper sets out a comparative study of various modal wavefront reconstructions for the Shack-Hartmann in the negligible scintillation regime. The Least Squares estimator has been shown to be equivalent to Maximum Likelihood (ML) for Gaussian noise and leads to an unbounded noise amplification. This drawback is usually overcome by restricting the modes to be reconstructed to an ad hoc 'small' subspace. It is equivalent to a regularization but the choice of the number of modes is critical and difficult. A Maximum A Posteriori (MAP) estimator outperforms the ML estimator by taking benefit of a priori knowledge of the statistical fluctuations of the phase. All these methods are compared on extensive simulations particularly in terms of noise amplification and aliasing. The DFWFS algorithm is presented that incorporates the wavefront MAP estimator.

Title **Wave-front phase estimation from intensity measurements: Need perimeter measurement**

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Abstract A means to directly calculate modal coefficients of a wavefront phase given irradiance measurements, with the Transport of Intensity Equation (TIE) is presented. This is done by use of basis functions called modal projectors obtained through the application of the generalized Green's Theorem to the TIE. The need of boundary conditions for the estimation of each mode component for uniform and non-uniform illumination is analyzed. Although the method is quite general, the discussion is primarily oriented for circular apertures, rotationally symmetric illumination and Zernike polynomials.

Title **Phase retrieval of wave packets**

Name Ulf Leonhardt, KTH, Stockholm, Sweden

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Abstract Quite often, the spatial phase profile of a wave is not directly observable, for fundamental or practical reasons (in quantum mechanics or optics, respectively). However, the spatial variation of the phase governs the wave dynamics. Therefore, one can infer the phase structure from the knowledge of the wave propagation. The paper discusses one general method [Leonhardt and Raymer, Phys Rev. Lett. 76, 1985 (1996)] of state reconstruction and generalizes this technique to situations when waves travel in time-dependent potentials.

Title **Liquid-crystal Hartmann Wavefront Scanne**

Name Vincent Laude, Ségolène Olivier, Carine Dirson and Jean-Pierre Huignard

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Abstract The original Hartmann wavefront sensing principle is implemented using a programmable liquid-crystal display (LCD) that is used to scan an incoming wavefront. The LCD displays sequentially the sampling aperture at many positions, say 32 by 32, across the wavefront pupil, and the position of the diffraction pattern behind lens is measured and memorized throughout this scanning process. From these data, the wavefront can be estimated in a modal or zonal way, much like with a Hartmann-Shack sensor. Compared with the former, the wavefront scanner is much slower and assumes a static wavefront, but its sampling characteristics can be programmed arbitrarily. A first experimental demonstration of this principle will be presented and commented.

Title **Fast phase FLC light modulator**

Name Eugene P.Pozhidaev, Igor N.Kompanets, Alexander L.Andreev, Sergei A.Shevchenko

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Abstract FLC based high speed phase light modulator was designed and studied. The effective phase light modulation is achieved due to DHF-effect (Deformed Helix Ferroelectrics) in conditions when the amplitude modulation is negligible. Then the birefringence magnitude change Δn during 400 ms under driving voltage not more than 5 V at the temperature interval of -20...+55 C is provided. Since the electrooptic response depends on a frequency of supplied alternating electrical voltage it is possible to increase the light phase modulation rate up to 1 kHz without essentially decreasing the birefringence modulation depth. Such modulators including spatial ones can be used for the wavefront correction in systems of adaptive optics, image formation and pattern recognition.

Title **Indirect wavefront sensing by dithering**
Name Gordon Love, Nathan Doble, David Buscher and Richard Mye
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Abstract It is not always necessary to determine the wavefront errors directly with the use of a wavefront sensor. Indirect methods involve monitoring the resultant image as the applied correction varies and searching for an optimum PSF. We will discuss the technique of dithering with reference to the correction of non-common path errors in the ELECTRA astronomical adaptive optics system.

Title
Name Malcolm Northcott
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Address University of Hawaii.
Abstract The curvature wavefront sensing technique has been successfully employed both for adaptive optics, and for high spatial resolution wavefront measurement. At the University of Hawaii we have used curvature wavefront sensing as the basis of the Hokupaa adaptive optics system. We have also used curvature sensing to measure the optics of the UH88 inch, IRTF telescopes as part of successful secondary upgrade projects. The simplicity of the curvature sensor, its absolute wavefront measurement, and its ability to operate over a wide dynamic range are crucial to both applications. The SNR achieved with curvature sensing is similar to that of the classic Shack Hartman and other "ray tracing" techniques.

Title RECONSTRUCTION OF SINGULAR PHASE FROM THE MEASUREMENTS OF WAVE-FRONT SLOPES

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Abstract An analytical expression connecting the optical beam phase with the values of its partial derivatives is proposed to solve a problem of the phase reconstruction from the measurements of wave front slopes by Hartman sensor, shearing interferometer, and from the interference measurements of Noks-Thompson. This relationship is a consequence of the statement of a task to reconstruct the phase from the wavefront slopes as a boundary problem of mathematical physics and allows an analytical presentation of the coefficients of the phase expansion on a prescribed system of functions to be written. The derived analytical representations for the phase and mode components are used for numerical reconstruction of the singular phase characteristic of the optical speckle fields. The reconstructed phase consists of the regularized approximation which makes it possible to detect the position and orientation of wavefront dislocations and the singular part obtained from the measured wavefront slopes with allowance for the vortex properties of the phase gradient.

Title Wavefront reconstruction with phase-diversity method and its application to measurement of telescope aberration

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Abstract We conduct computer simulations on reconstruction of wavefront telescope pupil with phase-diversity method. An instantaneous wavefront is reconstructed from an on-focus and its defocus speckle images of a point star. In the wavefront reconstruction we do not fit the wavefront to Zernike polynomials, but retrieve the phase with phase unwrapping procedure. Averaging over many atmospheric perturbed wavefronts leads to the residual phase error, namely the aberration of the telescope.

Title **SLMs AS THE SMART DEVICES OF MODERN OPTICAL SYSTEMS**

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Abstract The spatial light modulator (SLM) based on photoconductor - liquid crystal (LC) structure consists of number of thin film layers sandwiched between two glass substrates: a photoconductor, LC layers, alignment layers, transparent electrodes. When used in the reflection mode SLM incorporates an internal dielectric mirror which effectively separates the laser writing space from the projection space thereby allowing simultaneous writing and projection. LC is well known as smart material that changes its properties under the influence of external influence. Usually they used to visualize the distribution of not uniform thermal, electrical, magnetic, acoustic fields or for chemical and radiation detection. In this paper a unique application of LC for mapping the light radiation distribution on photoconductor surface is described. If voltage is applied to the electrodes, it is divided between the photoconductor and LC according to the exposure. This enables the optical activity of the layer to be modulated to form an image. The SLMs are the key elements of modern optical systems. Applications of the SLM are based on the device capability to convert images from incoherent to coherent light, to convert wavelength, to control the phase of light wave, to amplify light intensity and to enhance image contrast. In these systems the SLMs can be used as both input devices and as real-time holographic device. The application of SLMs covers the wide field of optical data processing:- wave front correlation in adaptive optical systems;- identification systems;- image correlation systems;- signal and hybrid electro-optical processing systems;- recognition systems;- projection systems;- image brightness and contrast intensifier;- laser systems (FLC array for intracavity laser beam steering);- fast switching devices;- linear polarizers;- electrically controlled LC diffraction grating;- transmissive FLC optically addressed SLMs;- optical neural networks. The main characteristic of SLM based on different types of LC and photoconductor material and with special control are discussed.

Title **Shack-Hartmann sensor with high dynamical range for aspherical surface testing**

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Abstract A feature of the Shack-Hartmann sensor is its capability for the measurement of steep wave-front slopes. A technique for testing aspherical surfaces without the use of a null-corrector is described. For this application a Shack-Hartmann sensor has been developed which has a significantly expanded range of measurable wave-front slopes. The optical testing set-up, the developed algorithm for the dynamic range expansion and experimental results are presented in this paper.

Title **Comparative Analysis of Phase Retrieval and Shack-Hartmann Wavefront Sensing for Space Based Segmented Optical Control System**

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Abstract It is likely that future large scale (> 6 meter) space telescopes will utilize an actuated segmented primary mirror with an active optical control system. The control system could consist of one or more wavefront sensors, actuators on the primary, secondary and possibly a deformable mirror. In this paper we discuss our analytical and computational models for both a phase retrieval and a Shack-Hartmann based optical control systems. We discuss the advantages and disadvantages of each and compare and contrast them with our previous computer studies. As time permits we will also discuss the use of extended scene phase diversity for in-situ monitoring of wavefront quality.

Title **Optical Axis Position Detection for Shack-Hartmann Wavefront Sensor Fabrication using a Diffractive Optic**

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Abstract The distance from a lens array to the imaging detector is critical high accuracy measurements with a Shack-Hartmann wavefront sensor. This distance is often difficult to determine with large f /lenses because their focal spot diameter does not change substantially for small displacements on either side of the focal plane. This paper describes a method for using an array of off-axis lens segments to determine the location of the focal plane. Because the lenses are off-axis, changes in the distance from the optic to CCD result in focal spot position changes. By analyzing the focal spot pattern on a CCD, we were able to achieve 12 microns RM error in axial position measurement over a 1mm range with a 4x focal length optic made up of 100 micron square lenses.

Title **ALFA - Modal control topics**

Name Markus Kasper

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Germany

Abstract Adaptive optics with laser guide stars system ALFA uses a Shack-Hartmann sensor with various hexagonal lenslets and a deformable mirror with 97 actuators. Topics related to calibrating the system, reconstructing and compensating the turbulent wave-fronts are discussed. The main focus is a comparison between Zernike polynomials and the Karhunen-Loeve function not only in terms of a better adaptation to atmospheric turbulence, but the effects on observability and aliasing characteristics. Additionally we consider issues related to compensation in the feedback loop.

Title **The ALFA system - a status report**
Name Stefan Hippler
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Abstract The Max-Planck Institut for Astronomy (MPIA) and the Max-Planck Institut for Extraterrestrial Physics (MPE) have recently installed the adaptive optics system ALFA, which uses a laser guide star at the 3.5-m-telescope on Calar Alto, Spain. The AO system consists of a Shack-Hartmann sensor, a deformable mirror with 97 actuators, and runs up to loop frequencies of 1 Hz. We give a status report including the current performance of the system and a short overview of the scientific results.

Title **Separating the wavefront aberrations of high and low altitude turbulent layers**
Name Thomas Berkefeld
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Abstract The small corrected field of view of present Adaptive Optics systems can be enlarged by correcting the individual turbulent layers instead of the integrated wavefront distortion. This so-called multi-conjugate adaptive optics setup however requires separating the influence of the different turbulent layers. We present a new approach of measuring the individual wavefront distortion of two layers with only one Shack-Hartmann-Sensor situated in the conjugate plane of the upper turbulent layer. Based on a formula connecting the amount of scintillation with the C_n^2 -profile and the telescope aperture, this simple optical setup distinguishes the wavefront distortions of the two layers using intensity fluctuations caused by the low altitude layer. The separation error is calculated as a function of the C_n^2 -profile, the light level and the telescope- and AO-parameters. It is shown that the separation error is small for typical cases.

Title **Self calibrating wavefront sensing and automated wavefront compensation systems**

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Abstract Real-time adaptive optics systems can now be commercially b using commercial electronic and optical components. We have implemented a self-calibrating Shack-Hartmann wavefront sensor with the ability to change sensitivity, and dynamic range with quick change of its lenslet array. The detection camera can be interchanged to customize its spectral response, frame rate, and digitization. Also, the subsequent wavefront reconstructor can be chosen interactively according to a specific application. We will show some examples from our work in adaptive optics system wavefront control, and deformable mirror calibration.

Title **Object-independent wavefront estimation from focal plane data**

Name Stuart M. Jefferies, Julian C. Christou, E. Keith Hege

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Abstract We demonstrate the recovery, without a priori object knowledge, of the unknown wavefronts from multi-frame focal-plane data by use of a modified blind deconvolution algorithm. By modeling the object Fourier spectrum as an unprejudiced linear combination of the cross-spectra of the measurements and the power spectra of the complex pupil, we have reduced an under-determined problem to one which is exactly determined. The linear model of the object spectrum also produces a band-limited object estimate by Fourier inversion.

Title **Development of a curvature Adaptive Optics system for the
GI2T Interferometer.**

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Abstract We will present the status of the developement of the Curvature
Wavefront Sensor at Observatoire de la côte d'Azur and the study
of the implantation of a complete system, one for each telescope,
the REGAIN recombinator table of GI2T. A test bench is currently
under integration. Its purpose is to qualify, by the end of 1999, the
Wavefront Sensor together with the Deformable Mirror and the
Real Time control system; this bench will also be used for the first
test on the sky at the 1.52 m telescope of Observatoire de
Haute-Provence. Some simulation results will show the expected
improvement of the Signal to Noise ratio of the visibilities
measured with the GI2T equipped with Adaptive Optics.

Title **Development of a curvature Adaptive Optics system for the
GI2T Interferometer.**

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Abstract We will present the status of the developement of the Curvature
Wavefront Sensor at Observatoire de la côte d'Azur and the study
of the implantation of a complete system, one for each telescope, in
the REGAIN recombinator table of GI2T. A test bench is currently
under integration. Its purpose is to qualify, by the end of 1999, the
Wavefront Sensor together with the Deformable Mirror and the
Real Time control system; this bench will also be used for the first test
on the sky at the 1.52 m telescope of Observatoire de Haute-Provence.
Some simulation results will show the expected improvement of
Signal to Noise ratio of the visibilities measured with the GI2T
equipped with Adaptive Optics.

Title **OCT with Feedback to Compensate for the Curvature of Wavefront at the Back of the Eye**

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Abstract Due to the limited aperture of the eye, the wavefront at the back of the eye is curved. A feedback loop is added to the OCT system to synchronously correct the reference path length while transversely scanning the retina. The device needed to correct the reference path needs to work at twice the frequency of the ramp applied to the galvanometer scanner which does the transversal scanning. An original fast scanning system was devised based on two galvanometer scanners. The technique is proved on images taken from an eye model scanned at 500 Hz. Larger size images are sampled by the OCT when the loop is closed, due to the planarisation of the wavefront.

Title **OPTIMAL COMPENSATION AND IMPLEMENTATION FOR ADAPTIVE OPTICS SYSTEMS**

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Abstract The purpose of this paper is to develop a compensation algorithm based on optimal control system design, and implement the compensator on the ALFA adaptive optics system that operates on the 3.5 meter telescope at the Calar Alto observatory, (operated by the Max-Planck Institut für Astronomie (MPIA) in Spain). The compensation design problem is formulated as an optimal disturbance rejection problem in discrete-time, with the objective of minimizing the RMS wavefront phase error orthogonal to the piston mode. Because the ALFA system uses a modal compensation architecture, the optimal disturbance rejection problem decomposes into parallel SISO modal disturbance rejection problems. The modal disturbances are modeled as white noise passed through a finite dimensional filter. The parameters of shaping filters are identified from open-loop data. Each modal disturbance problem is then a LQG optimal control problem with no weighting on the cost. These can be solved in closed form for low order disturbance dynamics. The compensators that result

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Abstract The VULCAN Nd:glass laser system amplification generated ultra-high intensities with sub-picosecond pulses. A measurement of the wavefront quality of the 200 mm diameter beam line was carried out using a radial shear interferometer to investigate a possible reduction of the three times the diffraction limit spot size. We present the results of this investigation showing whether wavefront errors were static (optics), dynamic (thermal transient (shot related) in origin, and identify ways of correction. Furthermore, we present the results of the installation of a *Static Astigmatic Corrector* (SAC) on the CPA beamline that improved the focusability of the Vulcan system to less than three times the diffraction limit.

Title **A novel wavefront sensor for confocal microscopy**
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Abstract A confocal microscope permits 3-D imaging of volume objects by the inclusion of a pinhole in the detector path which eliminates out of focus light. This configuration is however very sensitive to aberrations induced by the specimen or the optical system and would therefore benefit from an adaptive optics approach. We present a wavefront sensor capable of measuring directly the Zernike components of an aberrated wavefront and show that it is particularly applicable to the confocal microscope since only those wavefronts originating in the focal region contribute to the measured aberration.

Title **WAVEFRONT SENSING BY PHASE DIVERSITY: A TUTORIAL**
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Abstract Phase diversity implies that an aberrated image is observed through two optical channels. One channel has an aberrating wavefront such as that caused by a turbulent medium and the second channel has an additional, diverse phase. Usually the diverse phase is quadratic, which is easily induced by defocussing the observed image. In this tutorial we review the math, show how the wavefront can be extracted even if the object is extended, and show the results of experiments and simulation.

Title **WAVEFRONT SENSING FOR SPARSE APERTURES**
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Abstract A sparse aperture uses many small apertures separated by large distances. Such an aperture is lightweight when compared to a large, one-aperture system but it has the same high-frequency resolution. In this paper we show how a distorting wavefront can be sensed by phase diversity imaging, where the recorded data are an in-focus and an out-of-focus image. We present the theory and show computer simulations of wavefront sensing and imaging of extended objects for randomly positioned apertures and for an array with three-fold symmetry.



Title **A SIMULATOR OF DECONVOLUTION FROM WAVEFRONT SENSING SYSTEMS**
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Abstract We have developed a software tool to simulate image restoration systems using deconvolution from wavefront sensing to overcome the degradation effects produced by a turbulent atmosphere. A Shack-Hartmann wavefront sensor is assumed to be used for the estimation of the instantaneous atmospheric OTF. A particular feature of this tool is the simulation of the wavefront sensor measurements: the lenslet focal plane fields for each distorted wavefront are evaluated by the Hopkins' integral algorithm, and photon noise as well as the effects of focal plane pixelization are taken into account. Preliminary results of this simulator are presented, for a low-dimension Shack-Hartmann sensor working under different levels of photon flux and turbulence strength, using an optimum minimum variance reconstruction algorithm.

Title **Blazed Holographic Optical Aberration Compensation**
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Abstract Conventional Deformable Mirrors have a limited throw and to
compensate the many waves of aberrations of a large aperture
membrane mirror we need to use holographic correction. Optic
addressed Spatial Light Modulators (SLM) have been used in
laboratory demonstrations to remove up to 200 waves dynamic
aberrations (ref Gruneisen).

The next step is to use blazed holographic dynamic correctors
more efficiently transform the aberrated beam into a well
compensated one, eliminating all other diffractive orders . We
going to report the results obtained using a combination of an
optically addressed, parallel aligned nematic liquid Crystal SL
and an electrically addressed SLM. Using these SLMs in
conjunction with a CCD video camera and a computer we wer
able to introduce and then correct for first order aberrations (ti
defocus, astigmatism) with up to 50 waves @ 543 nm, we also
used the blazed holographic correction technique to correct for
around 20 waves of aberrations on a 2" area of a membrane mi